REPORT DOCUMENTATION PAGE

Form Approved OMB NO. 0704-0188

1. REPORT DATE (DD-MM-YYYY)	2. REPORT TYPE	3. DATES COVERED (From - To)
19-07-2015	Final Report	1-May-2012 - 30-Sep-2014

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
Final Report: Interactive Computational Algorithms for Acoustic Simulation in Complex Environments	W911NF-10-1-0506
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
	611102

6. AUTHORS	5d. PROJECT NUMBER
Dinesh Manocha, Ming Lin	
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAMES AND ADDRESSES	8. PERFORMING ORGANIZATION REPORT NUMBER
University of North Carolina - Chapel Hill 104 Airport Drive, CB 1350 Suite 2200 Chapel Hill, NC　　　　27599 -1350	

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS (ES)	10. SPONSOR/MONITOR'S ACRONYM(S) ARO
U.S. Army Research Office P.O. Box 12211 Research Triangle Park, NC 27709-2211	11. SPONSOR/MONITOR'S REPORT NUMBER(S) 57384-CS.41

12. DISTRIBUTION AVAILIBILITY STATEMENT

Approved for Public Release; Distribution Unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

The objective of this project is to develop new interactive algorithms for acoustic simulation. The proposed research includes development of accurate numerical methods for the wave equation, fast solutions based on sound field decomposition or geometric propagation, and development of hybrid numeric/geometric solutions.. These include efficient acoustic simulation of low- and medium-frequency ranges using adaptive rectangular decomposition and use of ray-frustum tracing and visibility computations for geometric propagation. We will also develop parallel algorithms that can exploit the parallel capabilities of current multi-core

15. SUBJECT TERMS

acoustic simulation, computational methods

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	15. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Dinesh Manocha
UU	UU	UU	UU		19b. TELEPHONE NUMBER 919-590-6049

Report Title

Final Report: Interactive Computational Algorithms for Acoustic Simulation in Complex Environments

ABSTRACT

The objective of this project is to develop new interactive algorithms for acoustic simulation. The proposed research includes development of accurate numerical methods for the wave equation, fast solutions based on sound field decomposition or geometric propagation, and development of hybrid numeric/geometric solutions.. These include efficient acoustic simulation of low- and medium-frequency ranges using adaptive rectangular decomposition and use of ray-frustum tracing and visibility computations for geometric propagation. We will also develop parallel algorithms that can exploit the parallel capabilities of current multi-core CPUs and many-core GPUs for fast computations. We will use these algorithms for immersive acoustic simualtion for urban and other complex propagation environments. The PIs will also collaborate with Stephen Ketcham and Keith Wilson at USACE and transition the resulting technology to Army and DoD applications. Moreover, resulting technology will also be applicable to other direct battlefied applications including battle planning on the operational scale of a brigade combat team, real-time source localization and camera pointing from acoustic arrays on aerostats, and dynamic routing of surveillance aircraft such as helicopters and UAVs to minimize audibility.

Enter List of papers submitted or published that acknowledge ARO support from the start of the project to the date of this printing. List the papers, including journal references, in the following categories:

(a) Papers published in peer-reviewed journals (N/A for none)

<u>Received</u>   <u>Paper</u>

04/18/2015 30.00 Ravish Mehra, Nikunj Raghuvanshi, Lakulish Antani, Anish Chandak, Sean Curtis, Dinesh Manocha. Wave-based sound propagation in large open scenes using an equivalent source formulation, ACM Transactions on Graphics, (04 2013): 0. doi: 10.1145/2451236.2451245

09/15/2013 21.00 Ravish Mehra, Nikunj Raghuvanshi, Lauri Savioja, Ming C. Lin, Dinesh Manocha. An efficient GPU-based time domain solver for the acoustic wave equation, Applied Acoustics, (2 2012): 0. doi: 10.1016/j.apacoust.2011.05.012

09/15/2013 22.00 Anish Chandak, Micah Taylor, Dinesh Manocha, Lakulish Antani. Efficient finite-edge diffraction using conservative from-region visibility, Applied Acoustics, (3 2012): 0. doi: 10.1016/j.apacoust.2011.09.004

09/15/2013 24.00 Ravish Mehra, Nikunj Raghuvanshi, Anish Chandak, Don Albert, Keith Wilson, Dinesh Manocha. Validation of 3D numerical simulation for acoustic pulse propagation in an urban environment, The Journal of the Acoustical Society of America, (2012): 0. doi: 10.1121/1.4708474

09/15/2013 25.00 L. Antani, D. Manocha. Aural Proxies and Directionally-Varying Reverberation for Interactive Sound Propagation in Virtual Environments, IEEE Transactions on Visualization and Computer Graphics, (04 2013): 0. doi: 10.1109/TVCG.2013.27

09/15/2013 26.00 Zhimin Ren, Hengchin Yeh, Ming C. Lin. Example-guided physically based modal sound synthesis, ACM Transactions on Graphics, (01 2013): 0. doi: 10.1145/2421636.2421637

12/04/2012 14.00 Lakulish Antani, Anish Chandak, Lauri Savioja, Dinesh Manocha. Interactive sound propagation using compact acoustic transfer operators, ACM Transactions on Graphics, (01 2012): 0. doi: 10.1145/2077341.2077348

12/04/2012 15.00 Min Tang, Dinesh Manocha, Sung-Eui Yoon, Peng Du, Jae-Pil Heo, Ruo-Feng Tong. VolCCD, ACM Transactions on Graphics, (10 2011): 0. doi: 10.1145/2019627.2019630

12/04/2012 16.00 Charlie C.L. Wang, Dinesh Manocha. GPU-based offset surface computation using point samples, Computer-Aided Design, (02 2013): 0. doi: 10.1016/j.cad.2012.10.015

12/04/2012 17.00 Micah Taylor, Anish Chandak, Qi Mo, Christian Lauterbach, Carl Schissler, Dinesh Manocha. Guided Multiview Ray Tracing for Fast Auralization, IEEE Transactions on Visualization and Computer Graphics, (11 2012): 0. doi: 10.1109/TVCG.2012.27

12/04/2012 19.00 Min Tang, Dinesh Manocha, Miguel A. Otaduy, Ruofeng Tong. Continuous penalty forces, ACM Transactions on Graphics, (07 2012): 0. doi: 10.1145/2185520.2185603

TOTAL: **11**

Number of Papers published in peer-reviewed journals:

(b) Papers published in non-peer-reviewed journals (N/A for none)

<u>Received</u>   <u>Paper</u>

08/05/2011 6.00 Qiming Hou, Xin Sun, Kun Zhou, C Lauterbach, D Manocha. Memory-Scalable GPU Spatial Hierarchy
Construction,
IEEE Transactions on Visualization and Computer Graphics, (04 2011): 0. doi: 10.1109/TVCG.2010.88

09/15/2013 5.00 Anish Chandak, Micah Taylor, Dinesh Manocha, Lakulish Antani. Direct-to-Indirect Acoustic Radiance
Transfer,
IEEE Transactions on Visualization and Computer Graphics, (2011): 0. doi: 10.1109/TVCG.2011.76

TOTAL: **2**

Number of Papers published in non peer-reviewed journals:

(c) Presentations

Number of Presentations: 2.00

Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

<u>Received</u>   <u>Paper</u>

07/30/2011 1.00 Lakulish Antani, Anish Chandak, Micah Taylor, Dinesh Manocha. Direct-to-indirect Acoustic Radiance
Transfer,
IEEE Transactions on Visualization and Computer Graphics (TVCG). , . : ,

07/30/2011 3.00 JIa Pan, Dinesh Manocha. GPU-based Parallel Collision Detection for Real-Time Motion Planning,
Workshop on Algorithmic Foundations on Robotics. , . : ,

TOTAL: **2**

Number of Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received   Paper

07/15/2012   8.00   Jia Pan, Dinesh Manocha. Bi-level Locality Sensitive Hashing for k-Nearest Neighbor Computation,
2012 IEEE International Conference on Data Engineering (ICDE 2012). 01-APR-12, Arlington, VA, USA. :
,

09/15/2013 27.00   Zhimin Ren, Ravish Mehra, Jason Coposky, Ming C. Lin. Tabletop Ensemble,
the ACM SIGGRAPH Symposium. 09-MAR-12, Costa Mesa, California. : ,

09/15/2013 28.00   Pavel Krajcevski, Adam Lake, Dinesh Manocha. FasTC,
the ACM SIGGRAPH Symposium. 21-FEB-13, Orlando, Florida. : ,

09/15/2013 29.00   Sujeong Kim, Stephen J. Guy, Dinesh Manocha. Velocity-based modeling of physical interactions in multi-
agent simulations,
the 12th ACM SIGGRAPH/Eurographics Symposium. 19-JUL-13, Anaheim, California. : ,

09/15/2013   2.00   Min Tang, Dinesh Manocha, Jiang Lin, Ruofeng Tong. Collision-Streams: Fast GPU-based Collision
Detection for Deformable Models,
Symposium on Interactive 3D Graphics. , . : ,

09/15/2013   9.00   Sujeong Kim, Stephen J. Guy, Dinesh Manocha, Ming C. Lin. Interactive simulation of dynamic crowd
behaviors using general adaptation syndrome theory,
the ACM SIGGRAPH Symposium. 09-MAR-12, Costa Mesa, California. : ,

09/15/2013 10.00   Sean Curtis, Jamie Snape, Dinesh Manocha. Way portals,
the ACM SIGGRAPH Symposium. 09-MAR-12, Costa Mesa, California. : ,

09/15/2013 11.00   Wenxi Liu, Rynson Lau, Dinesh Manocha. Crowd simulation using Discrete Choice Model,
2012 IEEE Virtual Reality (VR). 04-MAR-12, Costa Mesa, CA, USA. : ,

12/04/2012 20.00   Jia Pan, Dinesh Manocha. Bi-level Locality Sensitive Hashing for k-Nearest Neighbor Computation,
2012 IEEE International Conference on Data Engineering (ICDE 2012). 01-APR-12, Arlington, VA, USA. :
,

    TOTAL: **9**

Number of Peer-Reviewed Conference Proceeding publications (other than abstracts):

(d) Manuscripts

Received   Paper

09/15/2013 23.00   Ravish Mehra, Nikunj Raghuvanshi, Lakulish Antani, Anish Chandak, Sean Curtis, Dinesh Manocha.
Wave-based sound propagation in large open scenes using an equivalent source formulation,
ACM Transactions on Graphics (04 2013)

09/15/2013 4.00   Jur van den Berg, Sean Curtis, Ming C Lin, Dinesh Manocha, Sachin Patil. Directing Crowd Simulations
Using Navigation Fields,
IEEE Transactions on Visualization and Computer Graphics (02 2011)

09/15/2013 7.00   Jie-yi Zhao, Min Tang, Ruo-feng Tong, Dinesh Manocha. GPU accelerated convex hull computation,
Computers & Graphics (8 2012)

09/15/2013 12.00   J. Pan, D. Manocha. GPU-based parallel collision detection for fast motion planning,
The International Journal of Robotics Research (12 2011)

    TOTAL: **4**

Number of Manuscripts:

Books

Received   Book

    TOTAL:

Received   Book Chapter

    TOTAL:

Patents Submitted

1. ~~Ravish Mehra, Dinesh Manocha, "Methods, Systems, and Computer Readable Media for Simulating Sound Propagation in Large Scenes Using Equivalent Sources," Filed 09/22/2014.~~
2. Lakulish Antani, Dinesh Manocha, "Aural Proxies and Directionally-Varying Reverberation for Interactive Sound Propagation in Virtual Environments", Filed 11/15/2013.
3. Ravish Mehra, Lakulish Antani, Dinesh Manocha, "Methods, Systems, and Computer Readable Media for Source and Listener Directivity", Filed 6/30/2014.
4. Hengchin Yeh, Lakulish Antani, Ming Lin, Dinesh Manocha, Ravish Mehra, Zhimin Ren, "Methods, Systems, and Computer Readable Media for Simulating Sound Propagation Using Wave-Ray Coupling," Filed 7/11/2014.

Patents Awarded

1. ~~Dinesh Manocha, Lakulish Antani, Anish Chandak, Micah Taylor, "Methods, Systems and Computer Readable Media~~ for Fast Geometric Sound Propagation Using Visibility Computations", Issued 09/30/2014. Patent Number 8,847,965.
2. Dinesh Manocha, Lakulish Antani, Anish Chandak, Micah Taylor, "Methods and Systems for Direct-to-Indirect Acoustic Radiance Transfer", Issued 03/31/2015. Patent Number 8,995,675

Awards

Graduate Students

NAME	PERCENT_SUPPORTED	Discipline
Ravish Mehra	0.50	
Carl Schissler	0.50	
Qi Mo	0.50	
Lakulish Antani	0.50	
Hengchin Yeh	0.50	
FTE Equivalent:	**2.50**	
Total Number:	**5**	

Names of Post Doctorates

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Names of Faculty Supported

NAME	PERCENT_SUPPORTED	National Academy Member
Dinesh Manocha	0.10	
Ming C Lin	0.05	
FTE Equivalent:	**0.15**	
Total Number:	**2**	

Names of Under Graduate students supported

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Names of Personnel receiving masters degrees

NAME

Total Number:

Names of personnel receiving PHDs

NAME
Hengchin Yeh
Ravish Mehra
Lakulish Antani

Total Number: **3**

Names of other research staff

NAME   PERCENT_SUPPORTED

FTE Equivalent:
Total Number:

Sub Contractors (DD882)

Inventions (DD882)

Scientific Progress

We developed many novel algorithms of sound propoagation in indoor and outdoor environments. These are based on geometric, numeric and hyrbid sound propagation. Details of these algorithms with images, results, papers and videos are available at:

http://gamma.cs.unc.edu/research/sound/

Technology Transfer

Some of the acoustic simulation technologies have been licensed to a spinoff company called Impulsonic.

The PIs have close interactions with researchers at USACE and ARL. We have provided software implementations of some of our algorithms to the researchers at these organizations.